An updated "Replacement Yield" model fit to catch and survey data for the South coast and for the West coast Kingklip resource of South Africa

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Abstract

A Bayesian "Replacement Yield" model is applied to the total annual catches and the survey abundance estimates for the South African kingklip resource off the South coast and that off the West coast over the 1986 to 2019 period. A posterior median replacement yield (*RY*) of 1 152 tonnes is estimated for the South coast and of 3 218 tonnes for the West coast; these values are suggested as upper bounds for the catch limit recommendations. Setting the catch limit at the 25th percentile of the posterior distribution results in values of 919 t and 2 986 t for the South and West coasts respectively. The corresponding posterior median rates of increase over the last five years are estimated at about -0.7% and 2% for the South and West coasts respectively.

Introduction

Brandão and Butterworth (2016) reported on difficulties in updating the simple "Replacement Yield" approach to modelling the dynamics of the South African kingklip resource of Brandão and Butterworth (2013) given the addition of updated and further data. In 2016, the approach of Brandão and Butterworth (2013) no longer provided satisfactory estimates of survey catchability q. Given the addition of further data, including those for years following 2016, this paper updates the simple RY approach of Brandão and Butterworth (2013) as the difficulties of Brandão and Butterworth (2016) fortunately do not recur. In this paper, the South and the West coast components of the kingklip resource are modelled separately. Trends in abundance over the last five years and replacement yields are also estimated.

Data

Inputs to the "Replacement Yield" model include the annual total catches for the trawl and the longline fisheries, and survey abundance indices. Annual catches and abundance indices from 1986 (the year from which survey indices are available) are used and these are listed in Table 1 for the South coast and Table 2 for the West coast. The total annual catches for 2019 were not available in time for the present analyses; however, to be able to include the information from surveys for 2019, the assumption has been made that total annual catches for 2019 will be the same as for 2018. No differentiation is made between the different gear types (old or new) and between vessels (the *Africana* or the industry vessel) used during the surveys because the data are not sufficient to be able to inform on any such differences. Both the longline catch data and the survey abundance indices for the South coast autumn surveys and the West coast summer surveys (recently kindly provided by McGahey and Somhlaba) differ slightly from those listed in Brandão and Butterworth (2016).

MODEL

Detailed specification of the RY model used is given in the Appendix. As in the RY assessment reported in Brandão and Butterworth (2013), a Bayesian estimation procedure has been implemented for the RY model to inform on trends in abundance over the last five years and the associated uncertainty in those estimates. This requires the specification of prior distributions for all the estimable parameters. Non-informative priors have been assumed for all these parameters for the South coast component. A lognormal prior was a for the q_i parameters for the West coast (see below), while non-informative priors have been assumed for the other parameters.

The bounds placed on the uniform priors and the parameters of the normal distribution prior for ln(q_i) are set out in Table 3. A Markov Chain Monte Carlo (MCMC) algorithm (as available in the ADMB package) has been used to generate random draws from the joint posterior distribution of the model parameters. As in Brandão and Butterworth (2013), a uniform prior has been assumed for the q_i parameters for the South coast, with the bounds of the distribution given by the 95% confidence limits of the MLE estimate obtained from the Hessian matrix. For the West coast, the Bayesian mean and standard deviation for the South coast autumn ln(q_i) has been used to provide the parameter values for the normal distribution prior for the West coast ln(*qi*)s, unlike in Brandão and Butterworth (2013) which used the South coast spring ln(q_i) for this purpose. However, assuming the South coast spring ln(q_i) for the West coast resulted in unrealistically high estimates of biomass, and estimates of the *qi*s close to zero. As the South coast autumn survey series is now the longer series given further recent surveys at that time of the year, it seems reasonable to now rather use the autumn ln(q_i) to provide the parameter values for the West coast ln(*qi*) priors. The resultant 95% probability intervals were calculated as the intervals between the 2.5th and the 97.5th percentiles of the posterior probability distributions.

Chains of length of 1 million iterations were generated, using the mode of the posterior as the initial parameter vector. The chains were “thinned” by taking every 100th value in the chain, and the results of the first 1 000 iterations were discarded to allow for a “burn-in” period. Convergence of the MCMC chains was checked using the Bayesian Output Analysis (BOA) package in R.

The distribution of the trend in abundance of the South Coast and of the West coast kingklip over the last five years was determined by estimating the slope of the regression fit against time to each realisation of the posterior distribution of the natural logarithm of the model biomass time series.

RESULTS AND DISCUSSION

Results of the Replacement Yield model based on the Bayesian estimation are shown in Table 4 for the South and in Table 5 for the West coast. The “fit” of the model to the South coast survey data is shown in Figure 1 and to the West coast in Figure 2. These analyses suggest that the replacement yield for South coast kingklip is 1 320 t, and 3 104 t for the West coast, compared to estimates to 1 614 t and 4 102 t respectively by Brandão and Butterworth (2013), and compared to the range of estimated values from 760 to 1814 t for the South coast and from 4253 to 2435 t for the West coast for a given range of *q* values for the autumn survey (South coast) and summer survey (West coast) reported in Brandão and Butterworth (2016).

The posterior means and medians of the average percentage change in abundance per annum (over the last five years) together with the associated 95% probability intervals are shown on Table 6. These suggest a recent average annual decrease of about 0.7% (95% PI (-2.9%; 1.7%)) in the abundance of kingklip on the South coast over the last five years, and an increase of 2% (95% PI (2.0%; 2.8%)) on the West coast. The posterior median estimates of abundance (over the last five years) and the 95% probability intervals are shown in Figures 3 and 4 for the South and West coasts respectively.

Table 7 gives the Bayesian mean, median and the 95% probability intervals for B_{1986} and *RY* for each coast, as well as the 25th percentile for *RY*.

An appropriate precautionary approach, given the simple nature of this analysis, would be to set catch limits at some percentile below 50% of the posterior distributions for RY, which would set 1 152 and 3 218 as the upper bounds on recommendations for the South and West coasts respectively. Setting the catch limit at the 25th percentile of the posterior distribution (as in 2013) would result in catch limits of 919 t and 2 986 t for the South and West coasts respectively.

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Brandão A and Butterworth DS. 2016. Results for a "Replacement Yield" model fit to catch and survey data for the South and West coasts kingklip resource of South Africa. FISHERIES/2013/SEP/SWG-DEM/51(rev).

Table 1. Annual catches (in tonnes) and abundance indices for the South African kingklip (in tonnes) on the **South coast** together with CVs obtained from surveys (separated by season) for the period 1986 to 2019. Values in bold denote biomass estimates obtained using the new rather than the old gear on *Africana*, while italicised values denote biomass estimates obtained from surveys carried out on an industry vessel and the underlined values refer to biomass estimates obtained from surveys carried out on the *Nansen*. (Source: McGahey and Somhlaba, pers. comm.)

Year	South coast					
	Trawl catches	Longline catches	Sep/Oct (spring) (0 – 200 m)		May/Jun (autumn) (0 – 500 m)	
			Biomass	CV	Biomass	CV
1986	399	7453	2 780	0.239		
1987	392	4504	3 416	0.182		
1988	408	3311			6 478	0.455
1989	223	2209				
1990	266	708	1 104	0.352		
1991	680	0	2 148	0.273	7 499	0.146
1992	676	0	1 692	0.218	3 064	0.399
1993	884	0	1 135	0.201	8 759	0.393
1994	1560	48	1 333	0.276	34 989	0.664
1995	1275	48	1 152	0.427	20 623	0.409
1996	1981	60			3 502	0.189
1997	2128	120			5 130	0.268
1998	1366	87				
1999	1737	171			11 350	0.611
2000	1465	103				
2001	2210	57	2 033	0.292		
2002	2479	202				
2003	2558	160	**4 291**	**0.586**	8 690	0.745
2004	2539	141	**497**	**0.360**	**716**	**0.346**
2005	1851	121			**7 472**	**0.886**
2006	1322	127	1 774	0.444	1 297	0.249
2007	1223	85	**958**	**0.272**	**3 297**	**0.475**
2008	1307	118	**4 896**	**0.204**	**3 066**	**0.220**
2009	958	140			**6 072**	**0.302**
2010	1057	149			7 347	0.349
2011	891	126			**4 879**	**0.392**
2012	1272	112				
2013	1 995	84				
2014	1 584	25			1 842	0.609
2015	1 441	28			1 353	0.266
2016	1 217	21			9 256	0.635
2017	1 412	2			-	
2018	1 231	10			-	
2019	1 231†	10†			**4 179**	**0.239**

† Catches are not yet available for these analyses, so that the same catches as for the previous year are assumed.

Table 2. Annual catches (in tonnes) and abundance indices for the South African kingklip (in tonnes) on the **West coast** together with CVs obtained from surveys (separated by season) for the period 1986 to 2019. Values in bold denote biomass estimates obtained using the new rather than the old gear on *Africana*, while italicised values denote biomass estimates obtained from surveys carried out on an industry vessel. (Source: McGahey and Somhlaba, pers. comm.)

Year	West coast					
	Trawl catches	Longline catches	Jan/Feb (summer)		Jul/Aug (winter)	
			Biomass	CV	Biomass	CV
1986	2287	1231	3 770	0.161	2 462	0.151
1987	2083	1948	2 874	0.192	5 251	0.243
1988	1519	2091	5 627	0.208	1 690	0.243
1989	1407	1607			1 082	0.337
1990	1002	557	4 079	0.265	1 311	0.451
1991	1271	0	3 537	0.300		
1992	1884	0	7 703	0.187		
1993	2207	0	10 366	0.186		
1994	1445	92	8 294	0.179		
1995	1863	65	7 505	0.257		
1996	1596	170	12 222	0.298		
1997	1972	155	6 100	0.218		
1998	1632	53				
1999	2104	141	14 958	0.299		
2000	2166	199				
2001	2651	183				
2002	2280	312	13 475	0.165		
2003	1870	317	14 428	0.312		
2004	1823	266	**7 637**	**0.182**		
2005	1790	255	**5 714**	**0.165**		
2006	1476	110	8 287	0.299		
2007	1213	105	**5 783**	**0.258**		
2008	1122	83	**5 027**	**0.137**		
2009	1153	138	**11 325**	**0.185**		
2010	1405	199	13 700	0.137		
2011	1540	212	**16 067**	**0.165**		
2012	1866	270	**7 463**	**0.169**		
2013	1 801	281	*7 751*	*0.275*		
2014	1 525	327	*8 848*	*0.154*		
2015	1 610	335	*11 705*	*0.333*		
2016	1 613	414	*7 929*	*0.194*		
2017	1 085	297	**5 124**	**0.284**		
2018	969	237				
2019†	969†	237†	**16 332**	**0.340**		

† Catches are not yet available for these analyses, so that the same catches as for the previous year are assumed.

Table 3. Prior distributions assumed for the estimable parameters for the Bayesian assessments (see text for the rationale for these choices).

Coast	Parameter	Distribution
South and West coasts	$\ln(B_{1986})$	U [2, 20]
South and West coasts	RY	U [0, 100 000]
South coast	$\ln q_{survey}^{spring}$	U [-3.532, -1.512]
South coast	$\ln q_{survey}^{autumn}$	U [-2.609, -0.557]
West coast	$\ln q_{survey}^{summer/winter}$	N(-1.838, 0.452)

Table 4. Posterior mode of estimated model parameters for the **South coast** component of the kingklip resource. 95% probability intervals calculated from the Hessian matrix are also shown.

Parameter estimates	South coast
-ln L: Total	53.68
-ln L: Survey (spring)	20.12
-ln L: Survey (autumn)	33.56
B_{1986}	37 400 (8 729; 66 071)
RY	1 320 (826; 1 814)
q_{survey}^{spring}	0.080 (-0.001; 0.161)
q_{survey}^{autumn}	0.205 (-0.005; 0.416)

Table 5. Posterior mode of estimated model parameters for the **West coast** component of the kingklip resource. 95% probability intervals calculated from the Hessian matrix are also shown.

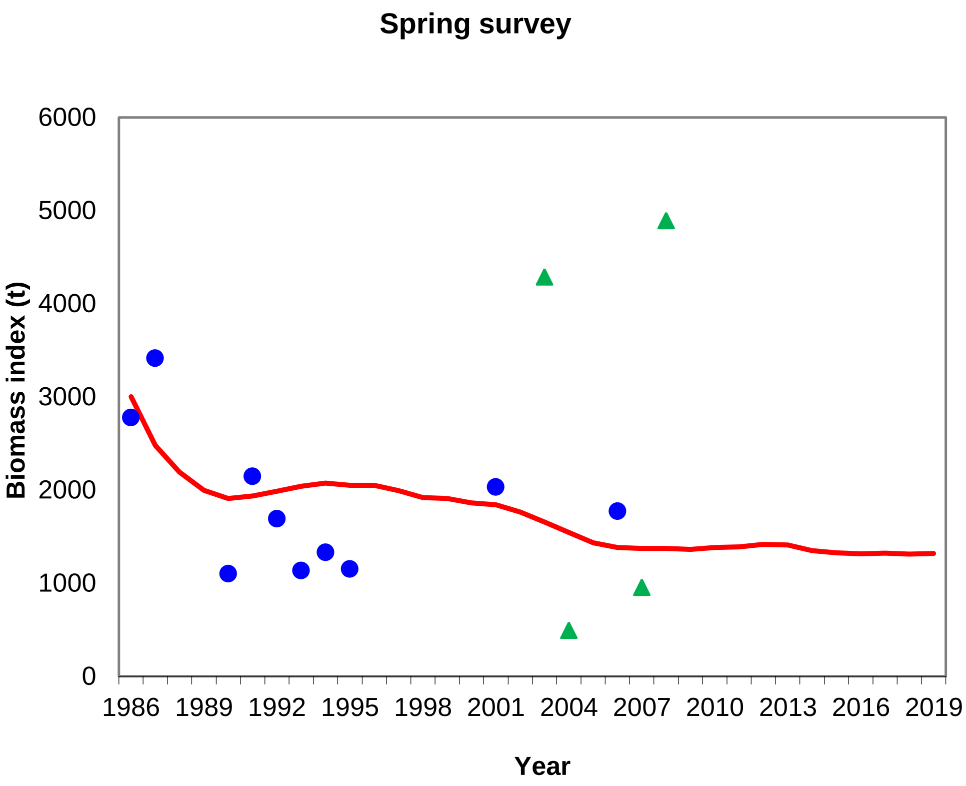
Parameter estimates	West coast
-ln L: Total	18.73
-ln L: Survey (summer)	14.88
-ln L: Survey (winter)	2.937
B_{1986}	27 913 (14 071; 41 753)
RY	3 104 (2 429; 3 779)
q_{survey}^{summer}	0.190 (0.085; 0.295)
q_{survey}^{winter}	0.089 (0.041; 0.137)

Table 6. Posterior means and medians of the average percentage change in abundance per annum (over the 2015 to 2019 period) obtained from the Bayesian analyses framework. The 95% probability intervals are also given.

Parameter estimates	South coast	West coast
Mean	-0.731	2.405
Median	-0.766	2.405
95% PI	(-2.923; 1.685)	(1.992; 2.820)

Table 7. Posterior means and medians for B_{1986} and *RY* obtained from the Bayesian analyses framework. The 95% probability intervals are also given.

Parameter estimates		South coast	West coast
B_{1986}	Mean	51 913	31 613
	Median	50 408	30 286
	95% PI	(26 093; 83 217)	(18 789; 52 486)
RY	Mean	1 109	3 285
	Median	1 152	3 218
	25th percentile	919	2 986
	95% PI	(455; 1 557)	(2 656; 4 293)



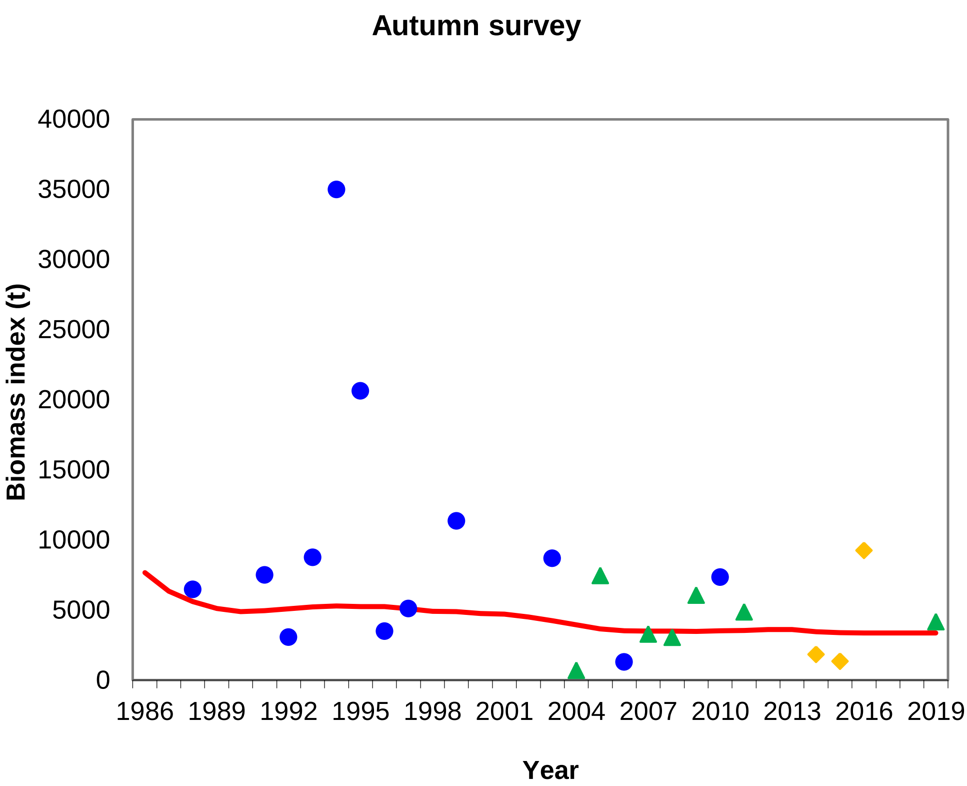


Figure 1. Observed (dots for the old gear, triangles for the new gear and diamonds for the industry vessel) values and the corresponding model estimated (line) trend for the *Africana* survey abundance indices fitted to data for the period 1986 to 2019 for kingklip off the **South coast** of South Africa.

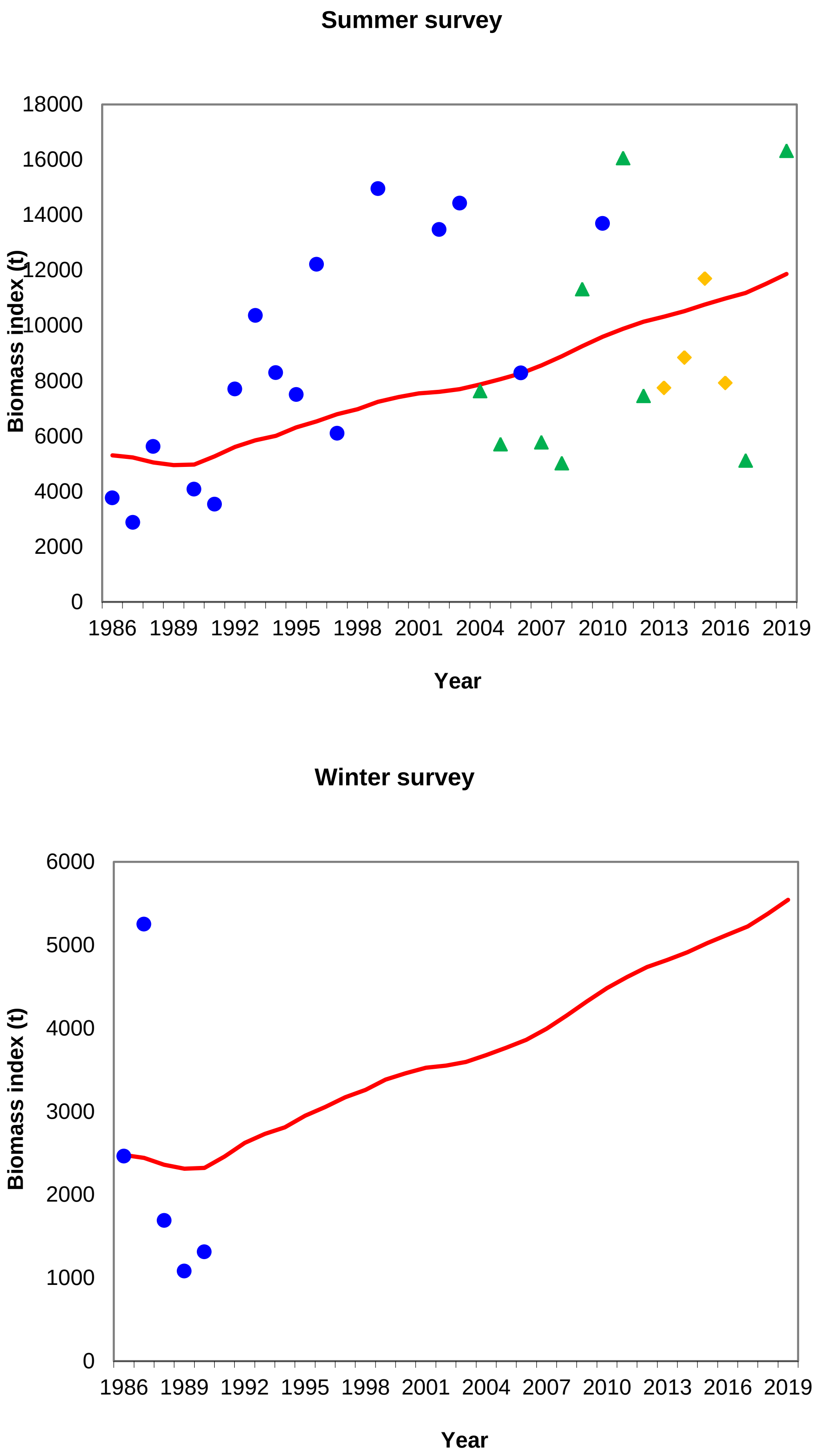


Figure 2. Observed (dots for the old gear, triangles for the new gear and diamonds for the industry vessel) and model estimated (line) trend of *Africana* survey abundance indices fitted to data for the period 1986 to 2019 for the kingklip off the **West coast** of South Africa.

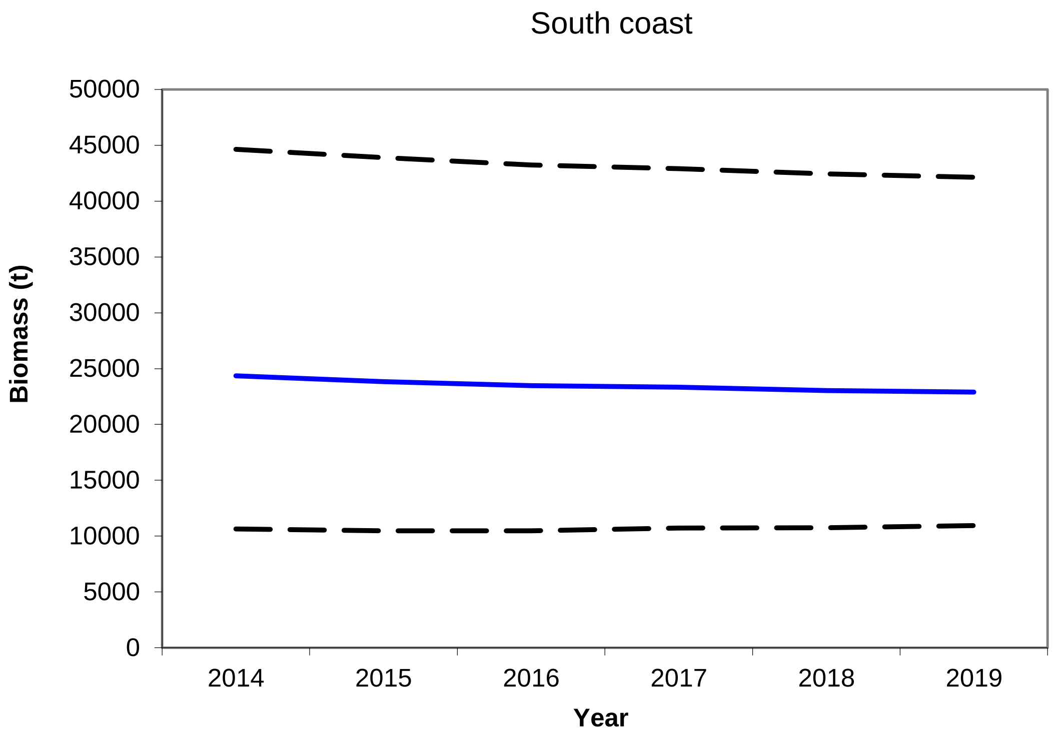


Figure 3. Bayesian posterior medians of abundance over the last five years for the **South coast** kingklip resource off South Africa. 95% probability interval envelopes are shown as dashed lines.

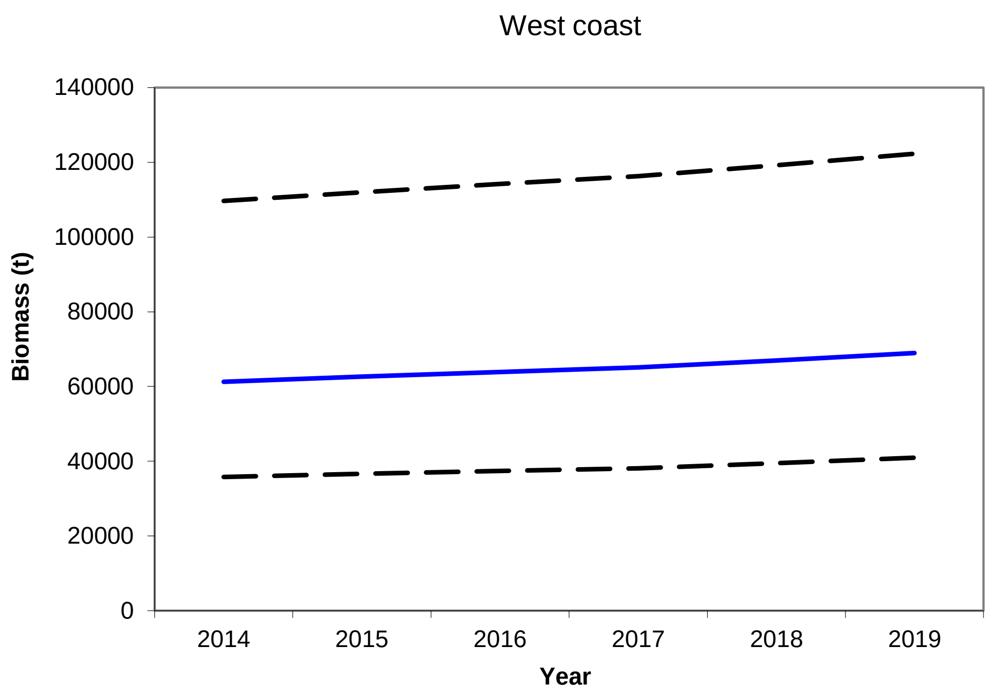


Figure 4. Bayesian posterior medians of abundance over the last five years for the **West coast** kingklip resource off South Africa. 95% probability interval envelopes are shown as dashed lines.

APPENDIX

REPLACEMENT YIELD MODEL AND LIKELIHOOD FOR KINGKLIP

THE POPULATION DYNAMICS

The kingklip resource dynamics are modelled by the following equation:

$$B_{y+1} = B_y + RY - C_y \tag{A.1}$$

where:

B_y is the biomass at the start of year *y*,

C_y is the catch in year *y*, and

RY is the replacement yield in year *y*, which is assumed to be constant over the period considered.

THE LIKELIHOOD FUNCTION

The model is fitted to survey abundance indices. Contributions by each of these to the negative of the log-likelihood ($-\ln L$) are as follows.

Survey abundance data

The likelihood is calculated assuming that the observed abundance indices are log-normally distributed about their expected value:

$$I_y^i = \hat{I}_y^i e^{\varepsilon_y^i} \quad \text{or} \quad \varepsilon_y^i = \ell n\left(I_y^i\right) - \ell n\left(\hat{I}_y^i\right) \tag{A.2}$$

where:

I_y^i is the abundance index for year *y* and survey series *i*,

$\hat{I}_y^i = \hat{q}_i \hat{B}_y$ is the corresponding model estimated value,

$\hat{q}_i$ is a constant of proportionality (catchability) for abundance index *i*, and

ε_y^i is the observation error for survey *i* in year *y*, which is assumed to be normally distributed: $N\left(0,\left(\sigma_y^i\right)^2\right)$.

For the surveys, an estimate of the CV is available for each survey and the associated σ_y^i are given by $\ln\left(1+\left(CV_y^i\right)^2\right)$, where the CV_y^i are the coefficients of variation of the resource abundance estimate for index *i* for year *y*. These CVs are input and are given in Table 1.

The contribution of the survey abundance data to the negative of the log-likelihood function (after removal of constants) is then given by:

$$-\ln L_{survey} = \sum_i \sum_y \left[\ln \sigma_y^i + \left(\varepsilon_y^i\right)^2 \Big/ 2\left(\sigma_y^i\right)^2 \right] \tag{A.3}$$

The catchability coefficient q_i for the survey abundance index *i* is estimated by its maximum likelihood value and is given by:

$$\ln \hat{q}_i = \frac{\sum_y \left\{ \ln I_y^i - \ln \hat{B}_y \right\} \left(1 \Big/ \left(\sigma_y^i\right)^2 \right)}{\sum_y 1 \Big/ \left(\sigma_y^i\right)^2} \tag{A.4}$$